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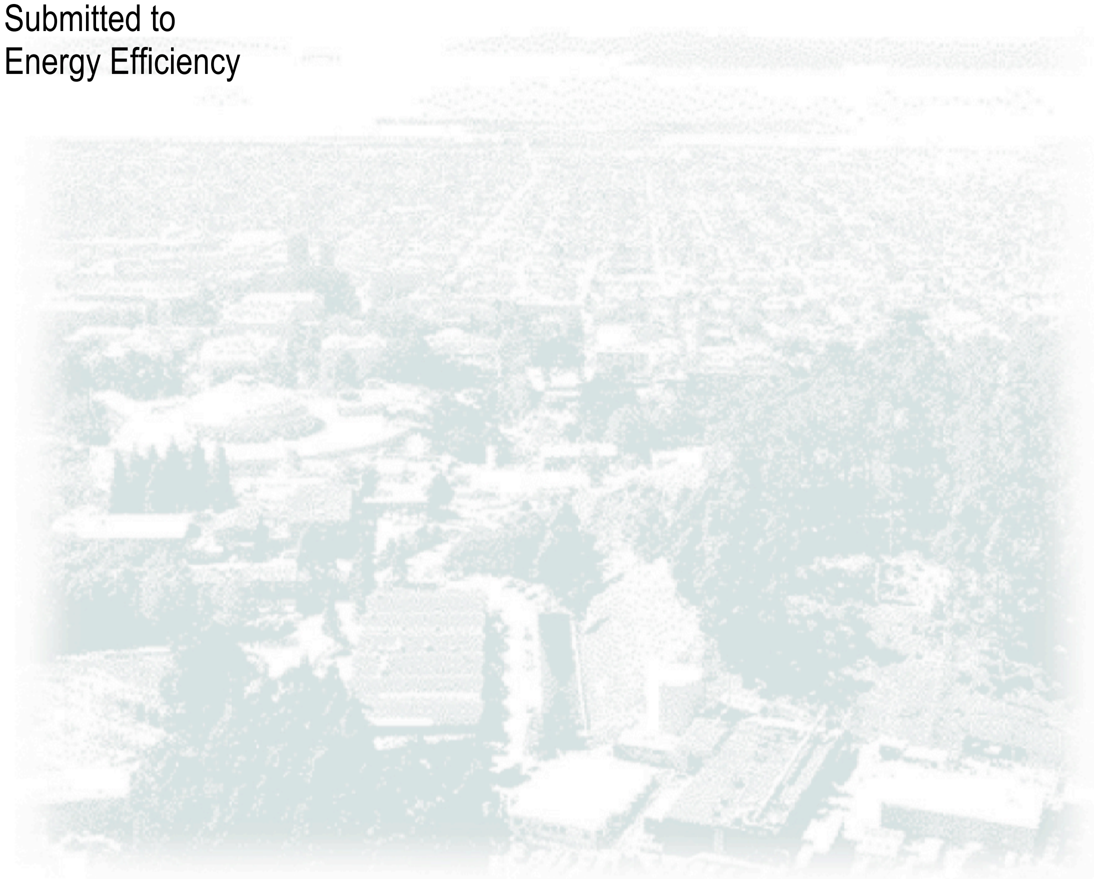

Field Demonstration of Automated Demand Response for Both Winter and Summer Events in Large Buildings in the Pacific Northwest

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Abstract

There are growing strains on the electric grid as cooling peaks grow and equipment ages. Increased penetration of renewables on the grid is also straining electricity supply systems and the need for flexible demand is growing. This paper summarizes results of a series of field test of automated demand response systems in large buildings in the Pacific Northwest. The objective of the research was two fold. One objective was to evaluate the use demand response automation technologies. A second objective was to evaluate control strategies that could change the electric load shape in both winter and summer conditions. Winter conditions focused on cold winter mornings, a time when the electric grid is often stressed. The summer test evaluated DR strategies in the afternoon. We found that we could automate both winter and summer control strategies with the open automated demand response communication standard. The buildings were able to provide significant demand response in both winter and summer events.

Keywords: Demand Response, automated demand response, OpenADR, dynamic peak load reduction

Abbreviations:

Demand Response (DR), Federal Energy Regulatory Commission (FERC), Bonneville Power Administration (BPA), Seattle City Light (SCL), Heating, ventilation and air conditioning (HVAC), Critical Peak Pricing (CPP), Energy Management Control Systems (EMCS), Demand Response Automation System (DRAS), outside air temperature regression (OATR), Seattle Municipal Tower (SMT)

Introduction

Demand response (DR) is a demand-side management strategy to reduce electricity use during times of high peak electric loads or when prices are high. The Federal Energy Regulatory Commission describes DR as "changes in electric usage by end-use customers from normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" (FERC 2009).

Technology to automate DR has been developed to improve the performance of DR programs by allowing the response to be more repeatable and reliable. This paper describes a set of field tests to evaluate the installation and performance of building control strategies that use a recently developed interoperable information exchange specification to enable fully automated DR. This automated DR signaling system is known as OpenADR, or the Open Automated Demand Response standard (Piette et al. 2009). OpenADR uses utility-provided price, reliability, or event signals to automatically trigger customers' pre-programmed energy management strategies.

This paper describes DR strategies used for both hot summer afternoons as well as cold winter mornings, both periods when electricity demand is typically high in the Pacific Northwest. The overall goal of the research was to develop, demonstrate, and evaluate automated DR technologies and strategies for commercial buildings in the Pacific Northwest. DR is an important least-cost resource for the northwest's Bonneville Power Administration (BPA) to meet peak demand. Although BPA has historically been able to meet peak load through the flexibility of its hydro system, continued load growth, wind power integration, and fish operations are stretching this capacity. DR is proven resource that can add both flexibility and capacity back to BPA's system. The tests were held in partnership with Seattle City Light (SCL), the municipal utility in Seattle, Washington.

The research described in this paper covers three primary areas. First, we describe the automation and communications technology used in the study. Second, we describe the methodology to collect whole-building electric load data and estimate the reduction in electricity use during the DR events. Third, we describe the five buildings included in the study, providing a description of the heating, ventilation and air conditioning (HVAC) plus lighting systems that were used to automate the demand response. The paper is organized as follows. The next section provides background and a summary of previous related DR research in commercial buildings including a summary of automation, electric load baselines, and literature on control strategies in non-residential buildings. The third section presents the methods used in the field study. The fourth and fifth sections cover results and discussions, with a final conclusion summarizing key lessons learned. This paper does not cover the cost analysis to install the automation, which was covered in the original project report (Kiliccote et al. 2010).

Background and Previous Research

Initial research on automated DR communications systems by the authors began in 2002 at the request of the California Energy Commission to help develop low-cost automation technology to reduce the possibility of future grid black outs. Another motivation for the automation was to assist the state to move toward dynamic electricity pricing to ensure that customers could automatically respond to high and varying prices. Such high prices might be provided to customers on hot summer days if the electric grid is near capacity (Borenstein 2005). Initial field tests of the DR automation systems began in 2003 with a field study in five buildings (Piette et al, 2005). Early research consisted of development and testing of communications technology as well as building controls strategies. Initial research has identified resetting zone temperatures as a promising technique to modify cooling loads on hot summer days (Motegi et al, 2007). Previous research has included evaluating different HVAC systems as well as examining the use of thermal mass to pre-cool buildings (Xu and Rongxin 2010). DR strategies for lighting systems vary based on the type of controls (Rubinstein and Kiliccote 2007). Research in Canada evaluated human factors with changes in light levels to understand if occupants could detect changes in set points. This work found that while some changes in lighting levels were detectable, it also demonstrated that they were acceptable to occupants tested in controlled environments (Newsham and Birt 2009). There has also been extensive research on developing baseline models to measure the change in electric loads from DR strategies (Goldberg and Agnew 2003). For commercial buildings, the outside air temperature regression baseline tends to be more accurate and less biased baseline than other models used by electric utilities (Coughlin et al. 2008).

DR program evaluations have shown that customers have limited knowledge of how to operate their facilities to reduce their electricity costs under critical peak pricing (Quantum and Summit Blue 2004). A similar challenge is that about 15% of the time, the person in charge of responding to the DR events is not at the facility, which is a significant obstacle to reliable manual response to DR signals (Quantum and Summit Blue 2004).

One objective of the automated DR systems was to provide automation at low cost by leveraging existing communications. Previous work has demonstrated how price-response can be automated using standard extensible markup language (XML) based communications with customer-owned control systems. The control systems were not retrofitted, only programmed for DR strategies. Fully automated DR accounts for more than 250 MW of peak demand savings in California. While this paper uses the OpenADR 1.0 technology, OpenADR 2.0 is just emerging as part of the National Institute of Standards and Technology Smart Grid Standards in the United States (OpenADR Alliance 2012). Figure 1 shows the basic architecture of OpenADR, which uses a client-server two-way architecture. The OpenADR clients linked or embedded in the building control system continuously, or every minute, receives signals from the communication server and responds that it has received the signal. The signals also contain "event pending" information to allow a control strategy to prepare for an event by using pre-cooling or pre-heating systems. OpenADR 1.0 provides an open application program interface for both the client and the communication between the utility system and the server.

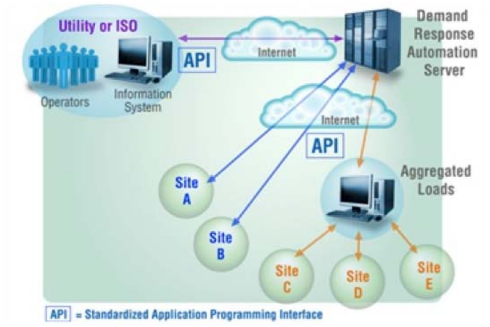


Fig. 1 OpenADR client-server design uses an open application programming interface

The automation server shown in the figure above can be located in the utility offices or at a remote data center. The OpenADR servers in California are located in San Rafael but provide the automation for southern and northern California through an agreement with a private company managing the system. The graphic shows a generic “aggregated load” which can also be geographically distributed. There is an aggregation company in San Diego that uses this model to provide OpenADR-based automation to small commercial buildings. The server in this case, as mention, is in northern California but the sites are in southern California. Given OpenADR tends to use Internet communications, the clients and services can be geographically distributed.

The electricity prices modeled in OpenADR programs have covered a variety of price information. The first pilots in the 2006 and 2007 translated critical peak pricing (CPP) that was offered from May through October in California. CPP tariffs had a normal, moderate and high-price period. The normal period was the majority of the hours. Moderate prices were fixed for noon to 3 pm in the afternoon and the moderate price was 3 times higher than the normal prices. The high price period was from 3 to 6 pm, and was 5 times the normal price. The OpenADR signal provided normal, moderate, and high price proxy information. OpenADR has a diverse set of data representations that can be customized by a utility to represent information in their DR program. OpenADR has, for example, a full representation of integer values such as $0.25/kWh to be provided in an OpenADR signal. The signal can contain “event pending” information that can inform a control system to prepare for a high price event that will occur the following day.

Methodology

This section outlines the design of the field test including a description of the recruitment of the sites, the automation systems, DR events and analysis methods including DR baselines for estimating the peak demand reduction

Sites

The project began with a recruitment phase that included the development of outreach materials for potential participants, surveys of existing electricity loads, and an assessment of 15-minute electric load data for winter and summer periods. The first winter tests were conducted in the early months of 2009. The summer tests were conducted in summer 2009. Five commercial building sites were recruited with a negotiated memorandum of understanding that described the sequence of the field tests. We collected building systems descriptions using a common site audit format and collected mechanical and electrical drawings when available. Most of the sites provided control system trend logs relevant to the analysis of the DR strategies. Each site had archived data from electric meters. In one case we installed an electric meter for the duration of the project. Each site was offered $3,000 for setup to join the project and $1,000 for participating in each event in the winter and $2,000 for setup and $500 for participating in each event in the summer. Although the summer incentives were smaller, all participants from the winter tests took part in the summer tests.

Automation

The DR signals for this project were published on a DR automation web services server, available on the Internet using the OpenADR signals. Each of the five participating facilities monitored the DR signal using a web services client application and automatically shed site-specific electrical loads when the proxy price increased. This project demonstrated use of the Open Automated

Demand Response Communication Specification (version 1.0), which is designed to facilitate DR automation without human intervention (Piette et al. 2009). Each site was outfitted to receive price proxy signals (or the associated operational mode signals) by one of two methods. If the site can host an embedded client in the Energy Management Control System (EMCS) software implementation is preferable. If no such controls were present a Client Logic Integrated Relay (CLIR) box would be installed (Piette et al. 2007). Each facility's EMCS vendor was hired to program the load-shed or shift control strategy to respond to the increase in the price signal.

During the winter and summer test periods SCL system operators determined the event start and end times. The DR automation server (DRAS) was programmed to send the DR test notifications to each participant. Winter DR events started at 7 a.m. and ended at 10 a.m. The events were dispatched based on the minimum outside air temperature during the DR period. At the beginning of each week, DR events were scheduled for the coldest days of the week as predicted in weather forecasts. Summer DR events started at noon and ended at 5 p.m. The summer events were called when the forecast temperature exceeded 26.7 ºC although one DR event was dispatched on a 25.6 ºC day because the team thought that there would not be any warmer days during the period.

For day-ahead tests, participants received notifications at 3 p.m. previous day, and, for day-of events, participants received notifications 30 minutes prior to the event start time. There were a total of four test events for each season: three day-ahead tests and one day-of test. During the winter tests, the test days for each site did not coincide because sites were tested as soon as they were enabled so the team could capture the coldest mornings. During the summer tests, sites were enabled around the same time, so more sites participated in each test event.

Each site was provided a prioritized list of potential DR strategies for the DR events. The price signals can be changed to "normal," "moderate," or "high," and the DR strategies can be tested as the price signals are changed. Commissioning this system entailed changing the price signals and observing the EMCS response. As soon as communication was established, the DRAS operator was notified so that the communications could be verified from the DRAS operator screen. Each site had a "mysite" automation page to allow facility managers monitor the status of signals coming into their control systems.

DR Events and Baselines

We called a total of 16 summer and winter DR events. Routine checking of the DRAS and client status along with the automated notifications when clients were offline meant that communication problems between the DRAS and clients or other issues related to client software/hardware were identified well in advance of DR events. The operator was responsible for monitoring the DRAS and status of all clients approximately every half hour to verify that there was no loss of communication between the DRAS and its clients. If the client went offline the customer were notified immediately to resolve any problems. We collected historical and event day electric load data for each site as well as outside air temperature data from the National Oceanic & Atmospheric Administration. These data were used to develop the three baselines model further described below:

- outside air temperature regression (OATR) model,
- the "three-in-ten" (3/10) baseline model, and
- the "average of similar days" baseline model.

The OATR baseline model is the most accurate, least biased model among the three for weather-sensitive buildings. However, collecting weather data from a site or a location close to a site is cumbersome and many electric utilities are unwilling to create weather-normalized baselines. Therefore, the 3/10 baseline model, which uses average hourly load shape of the three highest energy-consuming days during the 10 work days preceding the DR event of interest, is the baseline model preferred by utilities in California. Developing the 3/10 baseline does not involve collecting weather data, which simplifies the development process. The demand savings estimates for most of the buildings that participated in the study are based on the baseline OATR model. The exception is one building, which did not have historical electricity use data. For that building for the first events the average-of-similar-days model was used based on as many non-DR days as were available. If the model predicts a lower baseline than the actual demand for any given 15-minute or hourly period, this indicates negative demand savings. Negative demand savings are often found after a DR period as part of a "rebound" or recovery peak in which the HVAC system tries to bring the thermal zones back to normal conditions.

The evaluations performed include quantifying the demand savings in kilowatts (kW) at each site along with the savings in whole-building power reduction by percentage, and the demand intensity (W/m^2). The demand savings are calculated by subtracting the actual whole-building power from baseline demand. The demand savings percentage is defined as the percentage of savings in whole-building power. The demand-savings intensity (W/m^2) is the demand reduction (W) normalized by the building's floor area (m^2).

The model to calculate the summer afternoon demand reductions uses OATR with a scalar adjustment for the morning load (noted as OATR-Morning Adjusted, or OATR-MA in the graphics below). This methodology was utilized for the summer tests. However, for the winter tests, because the morning periods are when the Seattle DR events took place, a morning adjustment component was replaced and tested with an afternoon adjustment component because the afternoon periods capture and represent internal loads.

Outside air temperature regression model baseline

The electric consumption for the DR event period was subtracted from the baseline-modeled demand to derive an estimate of demand savings for each 15-minute period. Previous research recommends a weather-sensitive baseline model with adjustments for morning load variations for accuracy (Goldberg and Agnew 2003). For the OATR baseline, a whole-building power baseline was estimated first using a regression model that assumes that whole-building power is linearly correlated with outside air temperature. The model is computed as shown in equation 1;

$$L_i = a_i + b_i T_i \quad (1)$$

where L_i is the predicted 15-minute interval electricity demand for time i from the previous non-DR event workdays. Depending on the time interval of the available weather data, T_i is the hourly or 15-minute interval outside air temperature at time i. The parameters a_i and b_i are generated from a linear regression of the input data for time i. Individual regression equations are developed for each 15-minute interval, resulting in 96 regressions for the entire day (24 hours/day, with four 15-minute periods per hour. Time i is from 0:00 to 23:45). To develop the baseline electricity loads for determining demand savings, 20 "non-demand response" days were selected. These 20 baseline days were non-weekend, non-holiday, Monday through Friday workdays. Input data were 15-minute interval whole-building electricity demand and 15-minute interval or hourly outside air temperature.

Some utilities have used a 3/10 baseline for DR savings. The 3/10 baseline is the average hourly load shape of the three highest energy-consuming days during the most recent 10 work days (excluding holidays). The baseline algorithm for this project considers the site electricity consumption from 7 a.m. to 10 a.m. for the winter and noon to 5 pm in the summer when selecting the three days of highest consumption prior to a DR event. For commercial buildings, the OATR baseline is a more accurate and less biased baseline than the 3/10 baseline (Coughlin et al. 2008). Figure 2 is an example showing the Seattle Municipal Tower's participation in the March 3 DR event in 2009. The chart shows the actual whole-building power, the LBNL OATR baseline, and the 3/10 baseline. The vertical line at each baseline data point is the standard error of the regression estimate. The vertical lines at 7 a.m. and 10 a.m. identify the DR event period. On this day, the 3/10 baseline is higher than the OATR baseline because there were cooler days during the previous 10 days that were used to develop the baseline.

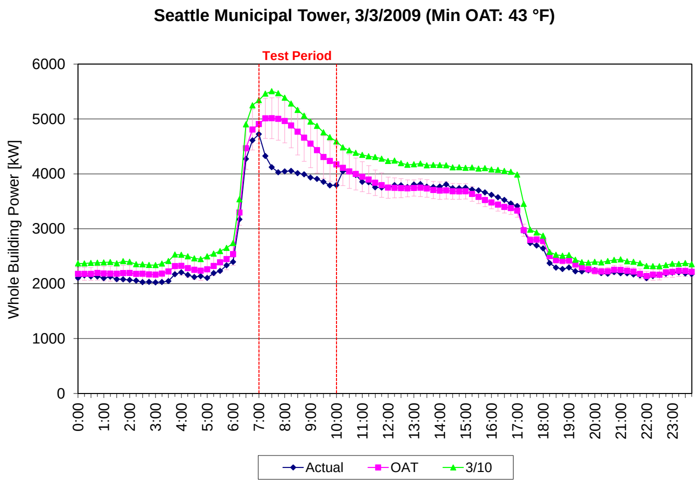


Fig 2. Example of Baseline Models and Actual DR Event day electric load for the Seattle Municipal Tower, March 3, 2009

An OATR baseline with adjustments (OAT_A) might be more accurate. In an OAT_A baseline, an adjustment factor (r_a) is multiplied by each 15-minute load. The factor r_a is defined as the ratio of the actual to the predicted load during the four hours in the afternoon preceding the winter DR event and four hours in the morning prior to the summer DR event, as shown in Equation 2.

$$r_a = \sum_{i=1}^{n} L_{a,i} \Big/ \sum_{i=1}^{n} L_{p,i} \quad (2)$$

Where r_a is the adjustment factor,

$L_{a,i}$ is the actual hourly average load on DR day at the hour's start at *i pm* ,

$L_{p,i}$ is the predicted load by baseline at the hour's start at *i pm*., and

n is the number of hours which are used for adjustment (*n*=4 for this analysis).

Average-of-similar-day baseline

For two sites interval meters were installed two days before the test events, the average-of-similar-day baseline was used because of the lack of prior data. For these sites, available data were averaged to develop the baseline. As the events progressed, the average used to develop the baseline included non-test days.

Results

Five buildings were recruited as listed in Table 1. The sites include two office buildings, two big box retail buildings, and one education facility.

Table 1 Name, Type, Size, Peak Demand and End-Use Systems in Five Test Buildings

Name	Type	Gross Area (m2)	Peak Load (kW)	Lighting	HVAC
Seattle Municipal Tower	Office	126,000	6168	Centrally scheduled with sweeps	Electric heat, 690 VAV boxes, 48 AHUs
Target – T1284	Retail	17,500	685	Central fixture switching (checkerboard)	Gas heat, 15 VAV RTUs
McKinstry	Office	10,530	347	Centrally scheduled with sweep	Gas heat with both 7 VAV and 16 CAV RTUs.
Seattle University	Education	10,505	941	Centrally scheduled with sweep	Electric heat, 102 VAV boxes, 4 AHUs, Cabinet and unit heaters
Target – T0637	Retail	10,463	225	Central fixture switching (checkerboard)	Gas heat, 15 VAV RTUs

VAV – Variable air volume; CAV- Constant air volume, RTUs – Roof top units, AHU – Air Handler Units.

Two participants, Seattle University and SMT, used CLIR boxes to communicate with the DRAS. McKinstry used a gateway device. Target developed a software client and embedded it into its enterprise control system in Minneapolis. Target stores have centralized DR capability through the enterprise control system. As shown in Table 2, two of the buildings are winter peaking and two are summer peaking. Winter baseline data were not available for one of the Target stores. The largest buildings are SMT and Target T0637. Seattle University has significantly lower summer demand intensity because the facility receives chilled water from the campus.

Table 2 Summer and winter peak demand for the five facilities*

Site	Summer		Winter	
	W/m^2	kW	W/m^2	kW
McKinstry	49	522	32	347
Seattle Municipal Tower	38	4921	48	6168
Seattle University	16	176	78	841
Target - T1284	44	784	30	534
Target- T0637	30	320	-	-

*Winter data for Target Store T0637 were corrupted

Table 3 lists 21 potential DR strategies that have been used at other facilities. The 12 strategies used in these 5 sites are identified with the winter (W) and summer (S) strategies listed. For building gas heat, the only potential savings from changing zone temperatures would be the savings from fan power in variable air volume (VAV) systems. When the heating set point is reduced, the fans that supply heat to a zone will temporarily slow down, which reduces electricity demand. The two Target stores with gas heated roof-top units participated with both lighting and HVAC strategies. SMT, which has all-electric heating and chillers for cooling, employed global zone temperature adjustment for both winter and summer with pre-heating and pre-cooling to prepare for the DR event. Only 26 of the 62 floors were programmed for the event due to lack of time for the control system programming. Seattle University, which receives steam and chilled water from the campus, selected preheating as a winter strategy. To do this, they turned off electrical heating units and adjusted temperature set points to reduce demand from the campus supply. McKinstry duty-cycled RTUs in the winter, adjusted temperature set points, and reduced lighting in the kitchen area.

Table 3 Summary of DR control strategies

	HVAC												Lighting					Other		
Site	Global temp. adjustment	Duct static pres. decrease	SAT decrease	Fan VFD limit	RTU Shut off	Duty Cycling RTUs	Pre-heating	Fan-coil unit off	Cycle electric heaters	Cycle AHU Fans	Cycle VAVs	Set up CO2 Setpoints	Common area light dim	Office area light dim	Turn off light	Dimmable ballast	Bi-level switching	Non-critical process shed	Elevator cycling	Slow Recovery
McKinstry																				
Target - T1284																				
Seattle Municipal Tower																				
Seattle University																				

W = winter strategy; S = summer strategy

Summary of OpenADR Technology Performance

By the beginning of 2009 four DRAS clients were operational for the project: two CLIR boxes and two software clients. No outages were experienced during either the winter season or the summer season. The CLIR and the software clients exceeded 99.99% reliability once the initial installation and integration were complete. There were two minor communication-related problems during the project. One was a malfunctioning CLIR box had been damaged during shipment. The box was replaced when communication could not be established. The other problem resulted from a change in the information technology (IT) setup at Seattle University, and the CLIR box was not brought on line by the IT department until the final IT configurations were completed. The delay in that case meant that the site had to trigger events manually until the last event. Thus, the last event called during the summer was the only event that was fully automated at Seattle University.

Summary of Event Days and Conditions

A total of 16 DR events were dispatched based on outside air temperature forecasts in 2009. Table 4 summarizes the DR event days, participation, and outside air temperatures. The first column shows the day of the week on which the site participated in the DR event. The second column shows the date of the event. If a site participated in the event, the cell associated with the date and site is highlighted, and the colors signify whether the event was day-ahead (blue) or day-of (yellow). The project team wanted to ensure that each site participated in three day-ahead events and one day-of event each season. The last column displays the minimum outside air temperature during the DR period in the winter and the maximum outside air temperature during the DR period in the summer.

Table 4 Summary of OpenADR winter and summer DR events in 2009

Day of Week	Date	Test	McKinstry	Target T1284	Target T0637	Seattle Municipal Tower	Seattle Univ.	Ouside Air Temp. (C)
Wednesday	18-Feb	Test 1	Yes	No	No	No	No	1
Tuesday	24-Feb	Test 2	Yes	No	No	No	No	1
Tuesday	3-Mar	Test 4	No	Yes	No	Yes	No	6
Thursday	5-Mar	Test 5	**Yes**	**Yes**	No	**Yes**	No	2
Monday	9-Mar	Test 6	No	Yes	No	Yes	No	1
Tuesday	10-Mar	Test 7	No	No	No	No	Yes	-2
Wednesday	11-Mar	Test 8	Yes	Yes	Yes	Yes	No	-2
Thursday	12-Mar	Test 9	No	No	No	No	Yes	-1
Monday	16-Mar	Test 10	No	No	**Yes**	No	**Yes**	3
Wednesday	18-Mar	Test 11	No	No	Yes	No	Yes	4
Friday	20-Mar	Test 12	No	No	Yes	No	No	3
Wednesday	19-Aug	Test 1	Yes	Yes	Yes	Yes	No	30
Thursday	27-Aug	Test 2	Yes	Yes	Yes	Yes	No	31
Friday	11-Sep	Test 4	No	Yes	Yes	Yes	No	28
Tuesday	15-Sep	Test 5	No	**Yes**	**Yes**	**Yes**	No	26
Tuesday	22-Sep	Test 6	Yes	No	No	No	Yes	31

Bolded cells indicate day-of DR event.

Summary of Winter Results

The field test described here is the first use of OpenADR employed to enable winter DR. Although Seattle's temperature swings between summer and winter are not extreme, it is a heating-dominant climate, and electric heating is widely used. On average, the buildings that participated in the winter study delivered 14% demand reduction or 5.5 W/m^2 over three hours. The best-performing winter site was Target [T1284], which consistently delivered 19% demand reduction. During the winter DR events, the sites delivered, on average, 767 kW demand reduction, which is 14% of the peak load (Table 4). The reductions resulted from demand shedding. Because loads were not deferred to other times of the day, 8.6 MWh of energy were saved during the winter DR events.

Table 5 Summary of winter OpenADR tests

Site	Test	Test 1	Test 2	Test 3	Test 4	Average
McKinstry	W/m2	2.3	1.5	1.4	2.5	1.9
	kW	25	16	15	27	21
	WBP%	9%	6%	5%	10%	8%
Target - T1284*	W/m2	4.7		4.7		4.7
	kW	102		104		103
	WBP%	19%		19%		19%
Seattle Municipal Tower	W/m2	5.3	5.6	1.7	3.72	4.1
	kW	678	717	220	477	523
	WBP%	15%	15%	4%	9%	11%
Seattle University	W/m2	13.1	9.5	11.8	10.4	3.3
	kW	141	102	127	112	121
	WBP%	20%	15%	19%	17%	18%
All Sites	W/m2				Average**	3.5
	kW				Total*	767
	WBP%				Average**	14%

Sheds are calculated using OATR model with no adjustments

* Total value is the sum of the averages for each site

** Average Value is the average of each site's average

During the winter DR tests, events were dispatched next day following the enablement of each site to capture cold winter morning responses. There was no single event in which all the sites participated. However, on March 11, four out of five sites participated in an event. The minimum outside air temperature during the DR period was -2.2 ºC. Because of a communication issue, data for two sites could not be collected on this date. Figure 3 shows the only aggregated demand savings during the winter tests, for the March 5 event the only event in which all sites participated. Average demand reduction per event of 767 kW (or 14%) was recorded using the outside air temperature baseline on March 5. This value is calculated by averaging the sum of each test day. The majority of savings results from the large peak demand savings at SMT. In aggregate calculations, the largest load typically dominates the aggregate shape. SMT has the highest loads among the project sites; thus, its load shape dominates the aggregate shape. This load shape is also representative of the winter morning peak problem in Seattle.

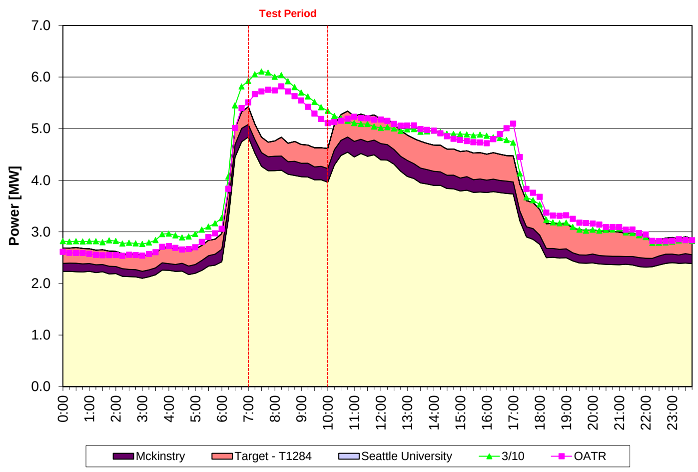


Fig. 3 Aggregate results from the DR event on March 5, 2009

Summary of Summer Results

The summer OpenADR test was better coordinated than the winter tests, so the sites participated in more events together. Therefore, more aggregated summer event results were calculated. The duration of summer DR events was increased to five hours as requested by the SCL operators. The summer study delivered, on average (i.e., average of each site's average), 16% demand reduction or 4.4 W/m^2 over five hours with a cumulative energy savings of 6.5 MWh. Table 6 summarizes the performance of each of the sites during these events. The average percent demand reduction at each of the facilities was calculated using the OATR baseline with adjustment for SMT, Seattle University, and Target T1284. For Target T0637, the calculation used an averaging baseline with morning adjustment. For McKinstry, we used the OATR baseline without the morning adjustment because we used pre-cooling as a DR strategy at this facility. Another facility that also practiced two-hour pre-cooling is Seattle University. Historical data for this site are lacking, so we are unable to calculate the OATR baseline, and the averaging baseline falls much below the measured data. Therefore, we used an evening adjustment calculated over four hours.

Table 6 Summary of summer OpenADR tests

Site	Test	Test 1	Test 2	Test 3	Test 4	Test 5	Average
McKinstry	W/m^2	0.7	3.7	7.3	4.7	4.7	4.2
	kW	8	40	79	51	50	46
	WBP%	2%	10%	21%	14%	13%	12%
Target - T1284	W/m^2	11.5	6.6	16.0	5.3		9.9
	kW	205	118	284	94		175
	WBP%	31%	22%	40%	19%		28%
Target - T0637	W/m^2	6.0	3.8	2.9	4.9		4.4
	kW	65	41	31	53		48
	WBP%	23%	18%	14%	21%		19%
Seattle Municipal Tower	W/m^2	-1.8	1.4	1.4	-		0.3
	kW	-232	186	180	3		34
	WBP%	-5%	4%	4%	0%		1%
Seattle University	W/m^2					3.3	3.3
	kW					35	35
	WBP%					21%	21%
All Sites	W/m^2					Average**	4.4
	kW					Total*	338
	WBP%					Average**	16%

Sheds are calculated using OATR model with no adjustments

* Total value is the sum of the averages for each site

** Average Value is the average of each site's average

Figure 4 shows the aggregated results from the September 11, 2009 (summer) test when aggregate results yielded the best savings. For the sites in the study, the peak occurs around 3 p.m. However, the peak demand is not as pronounced as in the winter. Seattle University is excluded from the aggregate results because that site was not fully automated until September 22. McKinstry implemented pre-cooling strategies two hours before events started. It is recommended that no morning adjustments be used for sites with pre-cooling strategies. Overall the average demand reduction for summer (338 kW) was more than half of the DR provided by the winter events (767 kW).

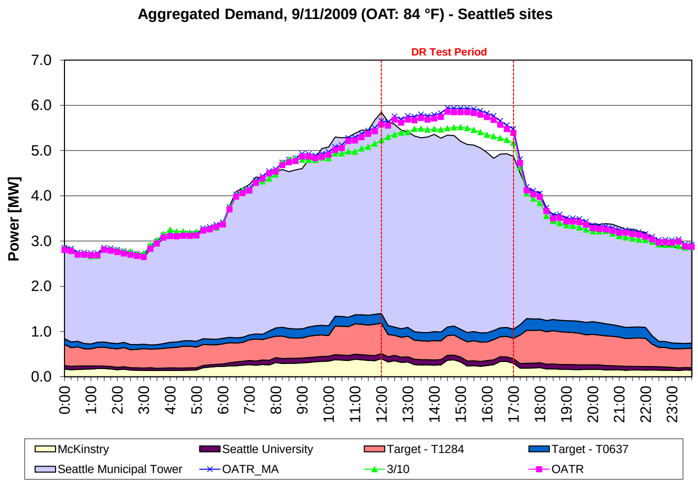


Fig. 4 Aggregate results from September 11, 2009

Day-Ahead versus Day-of DR Events

The amount of time between notification and actual start of a DR event affects the type and magnitude of the response in commercial and industrial facilities. Therefore, one of the four test events each season was scheduled as a day-of event so that we could observe how a facility's response differed between day-ahead and day-of tests. Among the participants, Seattle University implemented pre-heating in the winter and pre-cooling in the summer, and McKinstry experimented with pre-cooling in the summer; for these sites in particular, it would be instructive to compare the day-ahead results with pre-heating/pre-cooling with day-of results without pre-heating/pre-cooling. Unfortunately, neither McKinstry nor Seattle University participated in any day-of events during the summer. Seattle University did participate in three day-ahead events and one day-of event in the winter with pre-heating. Because the pre-heating period was short (only about two hours) and started at 5 a.m. (the building start-up time), it was difficult to see significant changes in the demand profile and savings from pre-heating.

Performance of Each Site

This section presents a series of comments about individual sites. McKinstry was the most challenging site. The savings from the winter tests were generally low because the building uses gas heating, so only limited savings were possible from the fans in the small number of RTUs that were cycled. Although small, the winter demand reduction was visible and consistently outside of the standard error of the baseline. On two of the five days of the summer tests, the building incorrectly went into heating mode; when this was realized, the set points were adjusted manually. The September 11 event was one of the two events when the heating mode was triggered; although significant savings resulted, the facilities group reported receiving many complaints from building occupants.

Target Store staff asked that we exclude lights around the fitting room from DR strategies. The Target team rewired the lights in the fitting room area so that they were excluded from being shut off during the DR events. Trend logs were collected from the controls, including zone temperatures serviced by the 12 RTUs. Figure 5 shows the zone temperatures on August 19. Although it takes four to five hours for a few of the zone temperatures to increase by 2.2 ºC, temperatures in a majority of the zones increased by 2.2 ºC within the first two to three hours and oscillated around the set point. The observed temperature increase was most rapid in the office and guest services areas and slowest in the pharmacy and conference room areas.

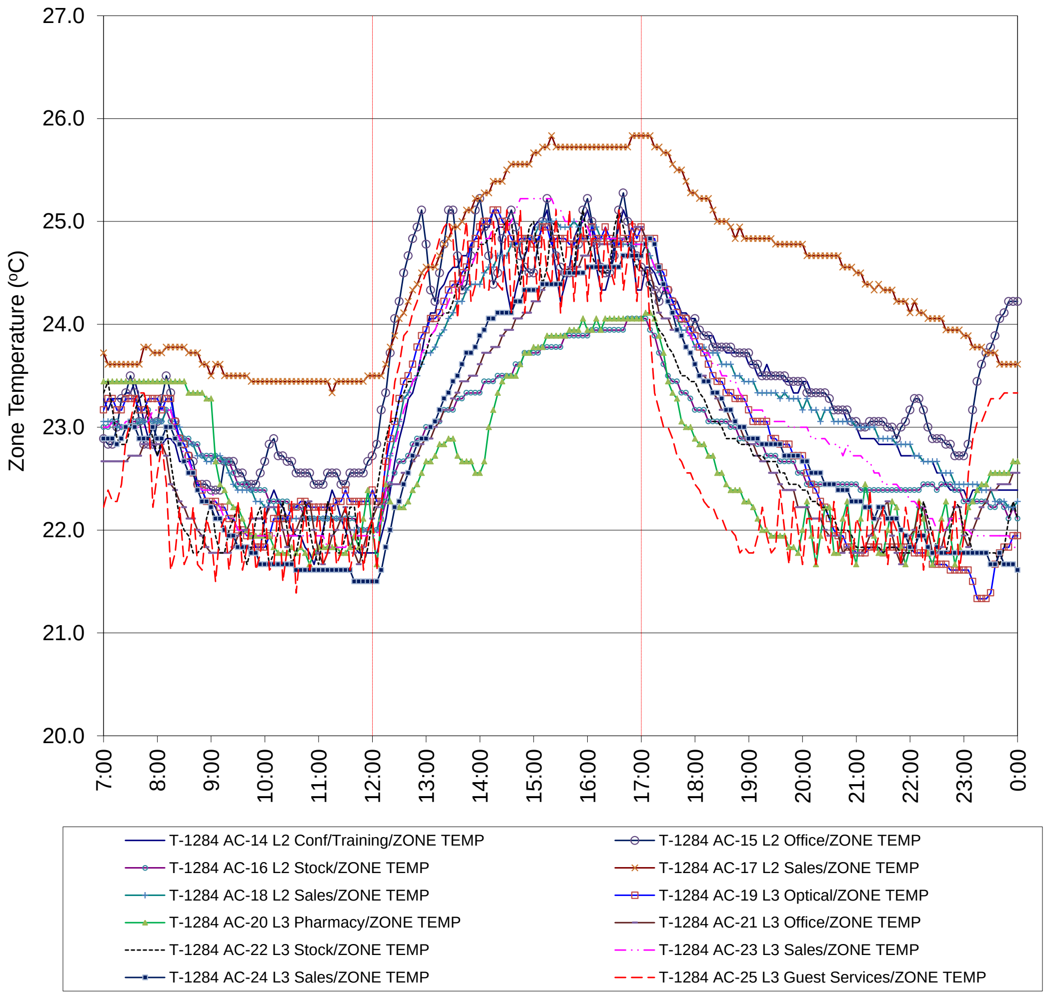
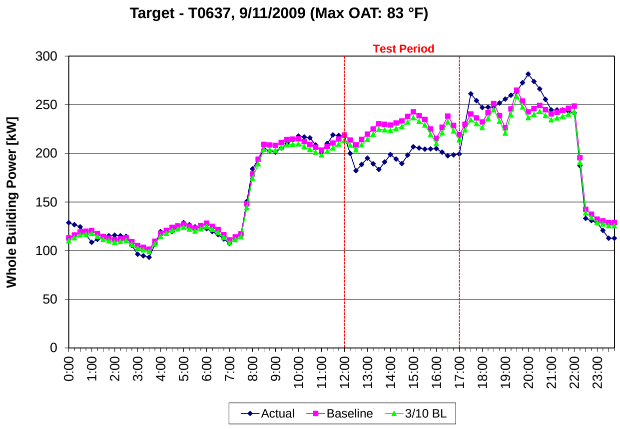
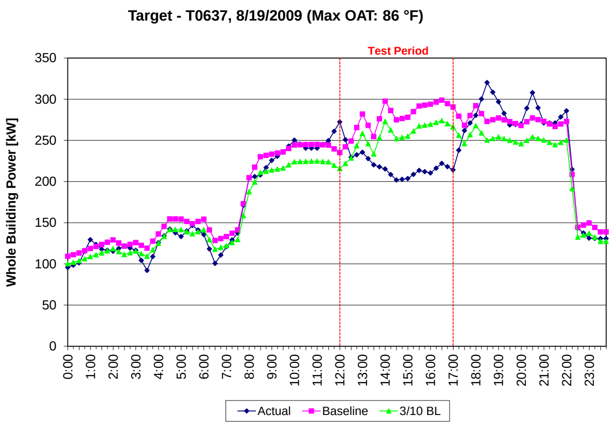


Fig. 5 Zone temperatures from August 19, 2009 DR event in Target (T1284). The DR event began at 12:00 and ended at 17:00

Although Target Store 0637 participated in winter and summer DR events, the winter meter data were corrupted, so we had to exclude them from the winter results (Kiliccote et al. 2009). However, this site continued to participate in DR events during the summer, and the meter data were captured for a few days before the events. Therefore, the averaging baseline was used to calculate the load sheds. This store is smaller than the other Target store in the study, and its load shape is also different. After the shed period, the measured demand was higher than the baseline, indicating a rebound in the first hour and higher demand in the following hours as shown in Figure 6.



6A: Load reduction on September 11, 2009



6B: Load reduction on August 19, 2009

Fig. 6 Min (6A) and max (6B) peak reductions days for Target (T0637) in 2009

Discussion

There are a number of key findings from the research that are important lessons for future DR programs and system designs. We list five key findings with a brief discussion of each.

Lighting provides year-round DR and can be automated for winter or summer programs. Lighting load-sheds have fast ramp times and thus can provide excellent year-round DR although the change in lighting level is detectable by building occupants. However, centralized controls are necessary for DR with lighting systems, and most lighting control systems are not centralized. Most new lighting control systems that integrate with daylighting in commercial buildings have local closed-loop controls.

All-electric heating systems offer good opportunities for winter DR. A global zone-temperature adjustment strategy, which is often used in California to reduce peak demand during summer afternoons, performed well in the electrically heated building in this study. Zone temperatures were temporarily reduced to minimize electric loads.

OpenADR systems can be used for both winter and summer DR in commercial buildings. This project is the only demonstration the authors are aware of in which the control system trigged an automated "winter" or "summer" strategy based on the mode of the HVAC system using OpenADR. On average, using the outside air temperature regression baseline, the buildings that participated in the winter DR events delivered 14% demand reduction per site or 5.3 W/m^2 over three hours. The summer DR events delivered 16% demand reduction per site or 4 W/m^2 over five hours. HVAC and lighting systems appear to present major opportunities for automated DR in commercial buildings for both winter and summer loads. In this study, both HVAC systems with electric heating and gas heating provided DR opportunities because there are significant savings from fan power. Average demand reductions for winter and summer events were 730 kW and 481 kW, or 12% and 8% of aggregate peak load, respectively.

Commissioning of DR strategies plays an important role in the success of DR in dual-peaking regions. During the DR tests, the sites did not have a way to trigger the event-pending signal through their interface ("mysite" webpage). The experience from the summer DR tests shows that customers need to be able to replicate all DR operating modes (DR event pending, DR strategy active, and DR strategy idle) to properly commission and test the DR control strategies. A significant finding is the importance of having the ability to trigger the pending signal manually, which was not possible in this test and caused problems for several sites. Commissioning of all of the signals improves the reliability of DR strategies.

DR works best in well-commissioned buildings. For one building where the DR performed well in the winter, the summer DR strategies did not perform well because the sequence of operations did not maintain zone temperatures.

Conclusion and Future Directions

This study has demonstrated the buildings in some regions of the country can participate in both winter and summer DR events and OpenADR based automation systems. The controls systems can support DR for both seasons. The majority of research in the US on OpenADR based systems has taken place in California and this demonstration shows the capability of these systems to perform in the Northwest. Overall, the average demand reduction for winter (767 kW) was more than twice that shown for the summer strategies (338 kW). Additional research is needed to understand how to equipment buildings with these DR automation technologies and allow them to participate in DR programs throughout the US and internationally. OpenADR 2.0 will allow many control companies to certify clients that are embedded in their control systems. Many utilities will need research such as that shown in this field test to understand the DR resources that commercial buildings can supply.

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